**Study of γ rays from Molecular Cloud Regions**

**γ rays ~ CRs x ISM (or ISRF)**

(Ackermann+12)

**Diffuse GeV γ rays are powerful probe to study the ISM**
- γ-ray production does not depend on the chemical and thermodynamic state of the ISM
- A good tracer of the total gas column density

“Conventional γ-ray analysis” (e.g., Ackermann+12)
- Fit γ-ray data with linear combination of three gas maps under the assumption that CRs uniformly thread the ISM
- “dark gas” (gas not traced by standard HI and CO observations) map is inferred by dust extinction map

\[
\gamma \text{ ray (l,b,E)} = q_{HI}(E) \times N_{HI}(l,b) + q_{CO}(E) \times W_{CO}(l,b) + q_{dark}(E) \times \text{dark gas}(l,b) + \text{background emission (IC, isotropic and point sources)}
\]
\( N_H \) Model and \( \gamma \)-ray Analysis

- Fukui+15 suggested \( N_H \) model based on linear function of the thermal dust optical depth \( \tau_{353} \)
- Roy+13/Okamoto+17 found nonlinear relation in Orion/Perseus molecular clouds
- We examined several \( N_H \) models as function of \( \tau_{353} \) with linear/nonlinear relations by fitting them to \( \gamma \)-ray data in the Chamaeleon region

\[ \tau_{1200} \propto (N_H)^{1.28{\pm}0.01} \]

\( \gamma \) ray \((l,b,E)\)
\~7 years \((0.25-100\ \text{GeV})\)
P8R2_CLEAN_V6

\[
\frac{N_H(l, b)}{N_{H,\text{ref}}} = \left( \frac{\tau_{353}(l, b)}{\tau_{353,\text{ref}}} \right)^{1/\alpha}
\]

(Reddening data obtained with 2MASS)

\[
N_{H}\ [10^{21}\ \text{cm}^{-2}] = q_H(E) \times \text{IC}(l, b) + I_{\text{iso}}(E) + \sum_{j} PS_j(l, b, E)
\]
Results (Residual Maps)

- Residuals in standard deviation ($\sigma$)
- Significant positive and negative residuals are seen in the models of $\tau_{353} \propto N_H^{1.0}$ and $\propto N_H^{1.6}$
- $\tau_{353} \propto N_H^{1.3}$ model provides the best fit to $\gamma$-ray data; lower residuals and the highest $\ln(L)$
- The nonlinearity may suggest grain evolution in the molecular cloud complex